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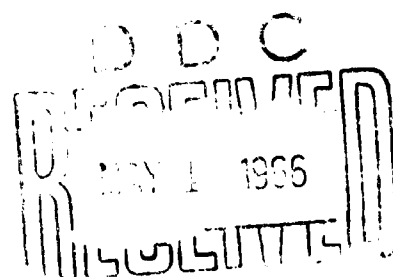
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## Chapter 19

### Apparatus Used in the Analysis of Luminescence

#### #99. Sources of Excitation for Luminescence

In the analysis of luminescence the most frequently applied method of excitation is photoexcitation; the method consists of exposing the analyzed object to either the short-wave part of a visible spectrum (the blue or violet rays) or to ultra-violet radiation. Ultra-violet excitation is superior because it is imperceptible to the human eye, thus neither the reflected nor the dissipated rays are hindering in the observation of the formed radiance.

The following can serve as sources for luminescence photoexcitation: The sun; the electric arc; electric spark; gas-filled electric lamps; in some cases, incandescent electric lamps.

The Sun Emission. For the purpose of the luminescence analysis of the sun emission only the band of from 400 up to 286 mμ, as separated by light filters is being used. Here a considerable part of the emitted energy comes also as a visible portion of the spectrum and has to be eliminated by means of light filters.

The electric spark is applied in those instances when, for the excitation purposes, one has to use a short-wave ultra-violet radiation (up to 185 mμ). At the same time the electric spark generates a significant number of visible rays. Often the spark is applied when conducting the luminescence analysis of minerals and crystallophosphors whose maximum absorption of the basic substance is situated in the extreme ultra-violet part of the spectrum.

The gas-filled electric lamps are the main lighting source for exciting the photoluminescence. In the gas-filled lamps, the ultra-violet rays are generated as a result of the electric discharge in a gaseous medium. This radiation has mostly a ruled spectrum characteristic of the lamp filling gas. Mostly, the mercury lamps are being used for the luminescence analysis. The magnitude of pressure at which the mercury vapors fill the bulb greatly affect the nature of the emitted spectrum.

To obtain a short-wave, ultra-violet radiation one has to use the low-pressure mercury lamps (0.01 mm of mercury column) with 15- and 30-watt heated electrodes. In lamps of this type about 70% of the total emission is concentrated in the mercury resonance line  $\lambda = 253.7$  mμ.

High-pressure (100-400 mm of mercury column) mercury-quartz lamps serve as a source of ultra-violet rays of both the near and medium diapasons of the wave-lengths. The Soviet industry manufactures high-pressure mercury lamps of different sizes (PRK-4, 240 watt; PRK-2, 375 watt; PRK-5, 240 watt; PRK-7, 1,000 watt) for either A.C. or D.C., and for 127 or 220 volts. In the above types of lamps the line  $\lambda = 365$  mμ has the highest intensity.

To make starting of mercury lamps easier a narrow metal strip "K" is attached to the tube outer surface; strip "K" is then connected to a condenser "C". In this case the lamps are connected to the power line through a starting device of a coil "L" and a condenser "C" (Fig. 189).

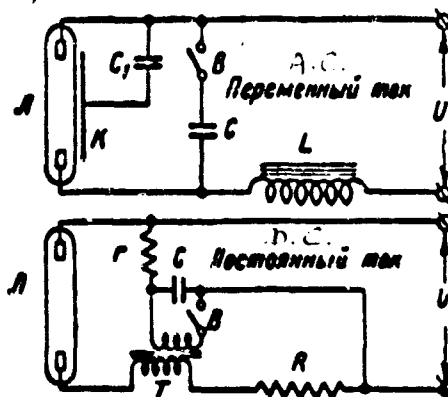


Fig. 189. Wiring diagram of high-pressure mercury lamp connected to either A.C. or D.C.

When the lamp is switched on the condenser "C" becomes charged and a certain difference of potential forms between the electrodes on one side and the strip "K" on the other; this potential difference starts ionization of mercury vapors inside the lamp and thus facilitates generation of an electric charge between the main electrodes. Mercury lamps also start when connected directly to the power line if a Tesla transformer is used.

Types PRK-2, PRK-4 and PRK-5 lamps which are manufactured with built-in starting devices can also be fed from a D.C. source. Here, starting will be effected according to an impulse scheme by way of closing and opening of disconnect "B" in the circuit of the impulse transformer "T" (Fig. 189).

To obtain high-power, long-wave ultra-violet emissions mercury-quartz lamps of super-high pressure are used (DRSh-100, SVD-120, SVDSH-250, SVDSH-500, SVDSH-1000); during a discharge in these lamps, the pressure of the mercury vapors can reach tens of atmospheres. Here mercury lines become washed out and the intensity of solid background will go up considerably.

When the super-high-pressure mercury lamps are used as the source of excitation during the photometric experiments it is extremely important to maintain a satisfactory stability of their emission. The main difficulty in this respect consists of the following feature - even with a highly stabilized electric feed of these lamps the image of their discharging band is constantly slipping over the surface of the object to be excited, thus hampering reading of the emission intensity. This harmful effect can be eliminated by means of an electronic stabilizing circuit which was described in chapter 16 (Fig. 164).

In some cases gas-filled lamps with a continuous ultra-violet spectrum are used. Of them the most widely used is the hydrogen-filled lamp. The Soviet industry manufactures two types of the hydrogen lamps - DVS-25, with a window of uviol glass (emission spectrum up to 200 mμ) and DVS-40, with a window made of quartz (emission spectrum up to 185 mμ). When higher intensities are required super-high-pressure lamps (type GSVD) filled either with krypton or any other inert gas (argon, xenon) are used. These lamps have a continuous ultra-violet emission spectrum of high intensity (from 400 down to 200 mμ).

For the purpose of the luminescence analysis, recommended are the modified 15-watt luminescent lamps manufactured in the shape of a tube made of uviol glass UFS-4, which lets through the long-wave ultra-violet rays and absorbs the visible

light. The tube is covered with crystallophosphor which emits an ultra-violet luminescence. During a discharge through the mercury vapors the crystallophosphor becomes excited and emits the ultra-violet radiation with  $\lambda_{\text{max}} = 350 \text{ m}\mu$ .

Incandescent lamps. These are rarely used as a source for ultra-violet rays. That is because not more than 1% of the total emitted energy is spent on the ultra-violet part of their spectrum; moreover, a considerable part of their ultra-violet rays is absorbed by the bulb itself. For the purpose of luminescence analysis, the incandescent lamps are used only in that case when it is practical to apply the short-wave portion of the visible spectrum, for example, when exciting a long-wave visible or infra-red luminescence. Here projection lamps with their flat spirals are often used.

Cathode tubes. When analyzing the luminescence of minerals and some types of crystallophosphori, the excitation is effected by means of cathode rays generated in cathode tubes, sometimes called "cathode cells". For this purpose cathode tubes, with either a cold or hot cathode, are used.

Cathode tubes with a cold cathode can be of various designs (Fig. 190 a). However, they are all shaped as a hermetically sealed container from which the air is pumped out until a vacuum of  $10^{-2}$ - $10^{-3}$  mm of mercury column is created. A cathode and an anode are built in the container, a window is provided in the body for watching the created luminescence. The substance to be tested is placed opposite the cathode, sometimes directly on the anode surface. A high voltage, from 2.5 up to 25 kv., is then connected to the electrodes. The flux of electrons emitted from the cathode starts luminescence.

The cathode tubes are manufactured in different shapes to suit individual purpose. Sometimes they are so small that they can be placed on a microscope plate; occasionally, they are made big enough to accomodate a sample of up to 10-15 cm in diameter. Cathode tubes with a hot cathode have a somewhat more complex design. Figure 190 b shows a simplified diagram of such a tube linked to a vacuum installation which can create vacuums down to  $\sim 10^{-6}$  mm of mercury column. The flux of electrons emitted from the incandescent spiral makes the sample luminesce.

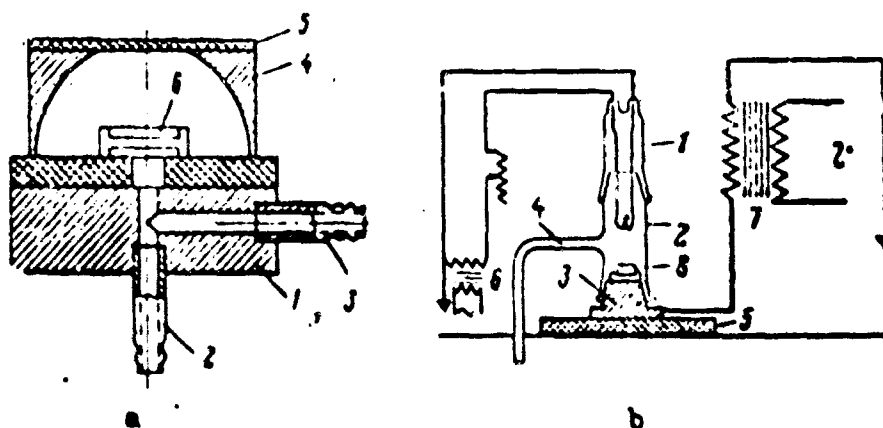


Fig. 190. Diagrams of installations for a cathode way of exciting luminescence: a - The Komovskii container: 1 - metal pedestal; 2 - connector with a vacuum pump; 3 - air inlet; 4 - metal container; 5 - glass window; 6 - cup where the sample will be placed. b - tube with hot cathode: 1 - section with the filament; 2 - the container; 3 - metal pedestal; 4 - connector with a vacuum pump; 5 - insulating pad; 6 - low-voltage transformer; 7 - high-voltage transformer; 8 - sample.

When carrying out a luminescence analysis on diamonds, minerals, glass and some types of crystallophosphors, the excitation is sometimes effected by means of Roentgen rays generated by the ordinary Roentgen tubes. In some instances the luminescence is excited by means of  $\alpha$  - molecules, protons, high-speed electrons and also x-rays (#114).

#### #100. Light Filters and Monochromators

To make the analysis successful it is very important that the rays of the exciting light do not coincide with the luminescence light of the sample and are not registered by the emission receiver. According to the Stokes-Lommel the luminescence spectrum is always shifted toward the long waves as against the spectrum of absorption. That is why the ultra-violet portion of the spectrum is used for excitation of the luminescence. However, all sources of the ultra-violet radiation are emitting also a considerable number of visible rays which, after having been reflected from the surface of tested substance, can enter the emission receiver together with the luminescence and thus distort its readings.

Light Filters. To eliminate the hampering portion of the spectrum, "light filters" which arrest the rays emanating from the exciting source, which are not necessary for the excitation itself, are used. The absorption filters are shaped as tablets and are made of colored glass, plastic, gelatin film, etc. Occasionally, liquid and even gaseous light filters are used. The liquid light filters consist of solutions of various inorganic salts ( $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ ,  $\text{K}_2\text{Cr}_2\text{O}_7$ ,  $\text{Ni}_2(\text{SO}_4)_3$ , etc.), as well as pigment solutions contained in vessels with either a glass or a quartz window.

The near ultra-violet portion of the spectrum is the most frequently used source of the radiance excitation. It is separated by means of the so called "black glass" which is made of uviol glass stained with nickelic oxide. The black glass remains non-transparent to the major part of the visible spectrum but easily lets through the ultra-violet rays. The Soviet industry manufactures four types of black glass (UFS) which allow separating of various spectral portions of the ultra-violet emission (Fig. 191).

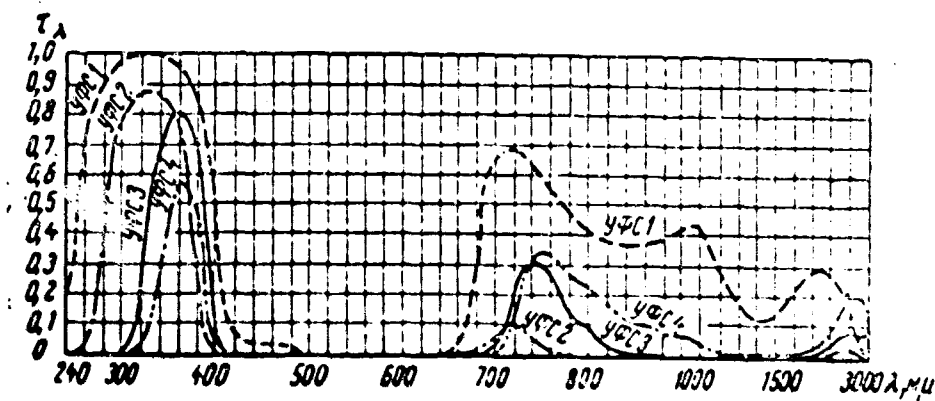


Fig. 191. Spectra passed through by 2-mm. thick filters made of black glass, type UFS.

The glass, type UFS-1, separates the band from 250 up to 400  $\mu$ . Filters UFS-2 let through a band 270 up to 330  $\mu$ . The above types effectively absorb the visible rays; they are given priority when it is not necessary to use the

18 short-wave portion of the ultra-violet spectrum. Filters UFS-3 (Wood's glass) separate the spectral band from 320 up to 400 m $\mu$ , and their "let-through" maximum is 360 m $\mu$ . Filters UFS-4 separate a band from 340 up to 390 m $\mu$ . They are highly heat-resistant, a feature which makes them superior to other types. Types FS of the glass are used for separating the short-wave portion of the visible spectrum.

All types of black glass can pass through the long-wave radiation starting from 650 m $\mu$  up (Fig. 191). In this range the sources of ultra-violet emission are characterized by a significant emanation which can seriously hamper the analysis itself, its interference is particularly acute when receivers are used which are sensitive to the red and infra-red rays. To absorb the long-wave radiation additional liquid light-filters consisting of diluted copper sulfate (CuSO<sub>4</sub>) with ammonia added, are used. The infra-red part of the spectrum can also be filtered by means of a 20-mm thick layer of distilled water, or by the heat-proofing, blue-green filters, types SZS-5, SZS-14 or SZS-15. Their advantage is that they easily pass through both the short-wave part of the visible spectrum and long-wave portion of the ultra-violet spectrum.

At present, more and more often used are the "interference light-filters" whose functioning is based on the phenomenon of a multi-ray interference. These filters consist of glass or quartz plates covered (by way of vaporization in a vacuum) with several alternating layers of metal (Ag) and dielectric or two different dielectrics (for example, ZnS and cryolite). In the visible range the above filters can separate spectral bands 25  $\text{\AA}$  - 10  $\text{\AA}$  wide with a coefficient of filtration at its maximum  $T_m$  60%. To attain even better monochromatic properties, with 25  $\text{\AA}$  - 1.5  $\text{\AA}$ , the complex interference light-filters which consist of two or more filters of the type described above, are used. In such case the value of  $T_m$  drops sharply and equals 10-15%.

3 The interference light-filters can be manufactured to suit the ultra-violet range. For this purpose the quartz plate should be covered with layers of PbCl<sub>2</sub>, Sb<sub>2</sub>O<sub>3</sub> and other substances, which alternate with layers of MgF<sub>2</sub> or cryolite. In the near ultra-violet range these filters can separate zones 25  $\text{\AA}$  - 10 - 15  $\text{\AA}$ . In such a case,  $T_m$  30%. With the filters having a wider range, say, 25  $\text{\AA}$  - 40  $\text{\AA}$ , the value of  $T_m$  will go up and will equal ~ 60%.

When working with mercury-quartz lamps which are characterized by only few widely-distributed lines, one has to apply combinations of various colored and black glasses. The Soviet industry produces sets of such filters which allow separating almost all principal lines of the mercury spectrum:  $\lambda = 578$  m $\mu$  (yellow line);  $\lambda = 546$  m $\mu$  (green line);  $\lambda = 436$  m $\mu$  (blue line);  $\lambda = 405$  m $\mu$  (violet line);  $\lambda = 365$  m $\mu$  and  $\lambda = 313$  m $\mu$  (ultra-violet lines).

Sometimes it becomes necessary to weaken the radiance of the sample without having distorted its spectrum. This can be attained by using the grids and "neutral light-filters" made of various types of the "NS" glass.

Monochromators. In some cases (when analyzing the multi-component solutions, when studying the spectra of polarization, etc.) it becomes necessary to excite the radiance by using separate monochromatic lines. This is achieved by means of monochromators. Depending on the spectral range to be separated monochromators

with either glass (for the visible part of the spectrum) or quartz and fluorite (for the ultra-violet part of the spectrum) are used. When a more intensive monochromatization is required double monochromators are used which consist of two series-connected single monochromators. The outlet aperture of the first one serves as an inlet aperture of the other. The double monochromator eliminates the dissipated rays; however, due to dissipation and absorption inside the apparatus, a considerable amount of light is lost.

#### #101 Photometers

Function and Construction of Photometers. In order to measure the radiance intensity of the samples photometers of different types are used (see Chapter 16). These devices are sometimes called the "fluorometers". The latter name is not acceptable as it coincides with the name of another apparatus which measures the duration ( $10^{-8}$  -  $10^{-9}$  sec.) of radiance of the molecular systems (see #104).

The photometric metering is based on a comparison between the brightness of radiance of the inspected sample and that of a calibrated source. For a visual photometering a human eye serves as the receiver; in the visible part of the spectrum the eye is very sensitive. When the radiance is adequately intensive the accuracy of the photometering can be 3-4% however, when the radiance is feeble and in the short-wave part of the visible spectrum, the error becomes considerable ( $\sim 10\%$  and more). Therefore, widely used are the photoelectric methods of photometry where photo-elements and photo-amplifiers (Chapter 16, #88) serve as light receivers. When metering the luminescence brightness, one should keep in mind that the photoelectric receivers are measuring the light flux emanated by the inspected sample. Therefore, the magnitude of the photocurrent will vary not just with the object brightness but also with its area, thus, one should either select objects of the same size or by means of diaphragms cut out identical fragments.

The photographic methods of the photometry are not accurate enough and are time consuming (see chapter 4, #15) consequently they are rarely used in the luminescence analysis. They might be useful where a documentary proof of the analysis is requested (for example, in a criminal case). Sometimes the above methods are applied for metering both the ultra-violet and infra-red luminescence as well as when studying a very weak radiance which can be recorded only after a lengthy exposure in a photographic process.

There are many different types of photometers on the market and they differ from each other in both design and principle of operation (chapter 16, #90). Here we will describe just a few of them, those which are most frequently used in the luminescence analysis.

The Universal photometer, type FM (see chapter 16, #90) is widely used in the luminescence analysis, its accuracy is 1-2-3% of the actual magnitude to be measured (Fig. 174). When measuring the luminescence brightness one of the illuminator windows is closed; the sample should be illuminated with light beams from the exciting source then, the brightness of the sample luminescence is compared with that of the calibrated source. By rotating the metering drum one can arrive at an equal illumination of both visual fields. Sometimes the illuminator is not being used, then, both the tested object and the calibrated sample are laid side-by-side on the table and both are excited from the same source thus, we can eliminate any chance of the radiance intensity being affected by the voltage fluctuations in the electric supply line.

### The Luminescence Photometer, type IFT-51

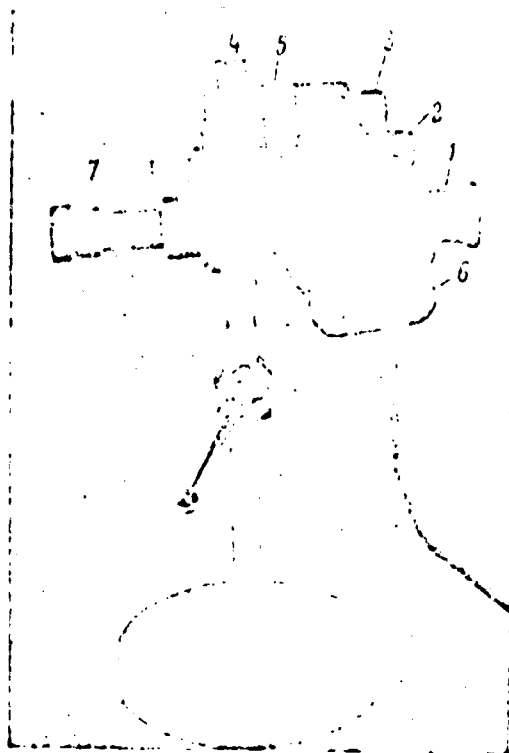


Fig. 192. The luminescence photometer, type IFT-51:  
1 - eyepiece; 2 - illuminator of the wedge scale;  
3 - lens of the wedge scale; 4 - housing with a  
circular neutral wedge and a calibrated scale;  
5 - handle for rotating the circular wedge;  
6 - rotating drum with three luminescing  
cartridges; 7 - the inlet aperture with an  
optical cap.

This photometer is suitable for metering objects with a very weak radiance and whose luminescence brightness varies from 0.02 up to 50 apostilbes\* (Fig. 192). This apparatus is equipped with a prism which divides the visual field in two equal parts. One-half of the field is illuminated by a calibrated luminescent light source, the other half by the light from the analyzed object. The brightness of both fields can be equalized by means of a circular neutral wedge. The calibrated light sources consist of three sets of light with a weak radiance but with its intensity constant (orange-colored, green and blue). Radiance of the calibrated sources has been excited by the emission which formed due to a natural disintegration of a radioactive substance which can be found in minute amounts in the light-sets. Depending on the spectral composition of radiance of the tested sample any of the three light-sets can be applied. In the field of vision the latter are generating the following respective brightness: For an orange-colored radiance 0.05 apostilbe; for the green radiance 0.3 - 0.4 apostilbe; for the blue radiance 0.03 apostilbe. When metering even weaker radiances by means of a neutral light filter the brightness of the calibrated source can be lowered to 1/35 - 1/50 of the original.

\* Apostilbe - unit of brightness: brightness of the surface which emanates 1 lumen of light flux from 1 sq. meter of area.



The Luminescence Colorimeter, Type LYUKS - 2 and the Luminescence Photometer,  
Type LYUF - 51

In their design the above apparatus resemble each other. The former is designed to quantitatively determine the amount of the luminescing substances in solutions, the latter, to quantitatively establish the amount of uranium in pearls\* of sodium fluoride. In both of the above apparatus a type PRK-4 mercury lamp from whose spectrum a UFS-3 filter separates the  $\lambda = 365$  m $\mu$  line, serves as a source of excitation. The ultra-violet rays are being focused either on two test tubes, one containing the tested substance, the other the calibrated solution (the LYUKS -1), or on tubes with the tested and calibrated pearls, respectively, as it takes place in the LYUF - 51 apparatus. By means of a special optical system the radiance of either of the objects to be compared is directed to one-half of the field of vision. The photometering is then carried out by way of polarization, using the polaroids, preliminarily the apparatus should be calibrated on standard solutions or pearls, which contain the luminescent substances or uranium, respectively, with a known concentration. Both of the above apparatus are very sensitive, for instance, the LYUF -51 can detect the presence of  $5 \cdot 10^{-10}$  gram of uranium in a sodium fluoride pearl weighing only 5 milligram, with an accuracy of  $\pm 20\%$ .

Recently a design was worked out for photo-electric photometers, type LYUF - 57 and FAS - 1, both of which have to establish the amount of uranium in alloys of sodium fluoride. In the LYUF - 57 photometer, a type SVD - 12A mercury lamp serves as the source of the exciting light and two alkaline photo-elements directed against each other, as light receivers. In the FAS -1 photometer a low-power mercury lamp, type UFO -4A, serves as the excitation source and the FEU - 19 amplifier, as the light receiver.

The maximum sensitivity of each of the two apparatus is  $1 \cdot 10^{-10}$  gram in a sodium fluoride pearl weighing 4 milligram. The same pearl measured in either of the two apparatus will give similar readings and their accuracy will be approximately 2% of the actual magnitude.

The Two-beam Photo-Electric Fluorometer, Type FM - 42 is designed to measure the quantity of uranium in pearls, tablets and powders.

Figure 193 shows the principle of operation of the above apparatus. By means of two mirrors (2 and 2') and through light filters (3 and 3'), the ultra-violet rays from a SVD - 120 lamp (1) are directed down two channels: The metering one - at the right and the compensating one - at the left, down the right channel through a variable diaphragm (4) the rays hit the sample (6) subjected to the analysis, excite its radiance by means of a spherical mirror (5) the latter is then directed to the photoelement "1", down the left channel through a photometric wedge (8) the rays hit a luminous plate (9) whose radiance will be recorded by the photoelement "2". Lest the exciting light affect the readings, two filters (10 and 10') interlocked with filters (3 and 3') are placed before

\* The name "pearls" was given to colored glass-like spheres which form during the reaction between oxides (or other compounds) of some metals and melted sodium tetraborate ( $\text{Na}_2\text{B}_4\text{O}_7$ ) or phosphate  $\text{Na}(\text{NH}_4)\text{HPO}_4 \cdot 4\text{H}_2\text{O}$ .

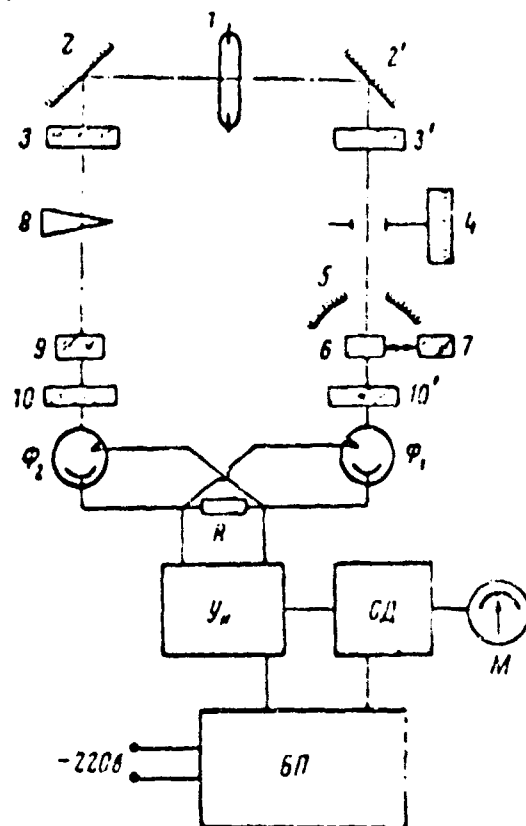


Fig. 193. The principle of operation of the FM - 42 fluorometer.

the photoelements  $\Phi_1$  and  $\Phi_2$  (see #107). The photo-currents from the photoelements  $\Phi_1$  and  $\Phi_2$  are flowing through resistance "R" in opposite directions; the signal voltage on the above resistance is then amplified by the amplifier "Y<sub>a</sub>", rectified by a synchronous detector, "CΔ", and directed to the meter "M".

During the metering procedures the sample (6) to be analyzed shall be introduced into the right channel, with the diaphragm (4) fully open; by varying the magnitude of the light flux in the left channel by means of the wedge (8) we can make the respective currents of the  $\Phi_1$  and  $\Phi_2$  photoelements equal. Next replace the sample (6) with the standard (7) which has been preliminarily calibrated on a sample with its uranium concentration known. The upset equality of the photo-currents will be restored by means of the diaphragm (4) and the reading on the latter's scale will determine the uranium concentration in the sample as a percentage of that in the standard.

The FM - 42 fluorometer allows measuring the uranium concentration in a sample in a range from  $10^{-8}$  up to  $10^{-5}\%$ . The error in the readings of the fluorescence brightness does not exceed 1-2%.

#### #102. Spectrographs and Spectrophotometers

In the luminescence analysis it is sometimes not enough to establish the integral radiance intensity of the sample and it becomes necessary to measure also the relative distribution of energy in its spectrum. This can be achieved by using the spectrographs, monochromators and spectrophotometers.

When carrying out the spectrophotometric metering of luminescent objects one should keep in mind that the integral intensity of their radiance usually

insignificant and after the radiance has been broken down in a spectrum for each individual wave-length the intensity becomes very small indeed, consequently it is of great importance that the apparatus has a considerable light power. Another peculiarity of the luminescence spectra consists in that for the majority of substances they present wide, featureless bands; while their magnitude is being measured the extent of the apparatus dispersion means very little. Therefore, when metering the spectra of luminescence, one should as a rule, use apparatus with a high light power and whose dispersion is not too high.

Spectrographs. Two Soviet-made types of spectrographs are recommended for use in the luminescence analysis. Suitable for measurements in the visible part of the spectrum is a made-of-glass, triple-prism, high-speed spectrograph, type ISP - 51 (or ISP - 53) with two interchangeable cameras having a focal length  $f_1 = 120\text{mm}$  and  $f_2 = 270\text{mm}$ ., respectively (for details see #8). For work in the ultra-violet field a quartz, high-speed spectrograph, type ISP -66 is recommended, it can handle the spectrum range from 2,000 up to 5,500 Å. However, in the visible field its dispersion is very low (780 Å/mm for  $\lambda = 6,563$ , and 190 Å/mm for  $\lambda = 4,046$  Å); the dispersion in the short-wave part of the spectrum becomes considerably higher (72 Å/mm for  $\lambda = 3,034$  Å, and 12.5 Å/mm for  $\lambda = 2,000$  Å). The most important advantage of the ISP-66 spectrograph is its high light power (the operating relative opening 1:4,6).

Spectrophotometers. The widely used spectrophotometer, type SF - 4 (see Chapter 16, # 90) is not adapted to registering of a luminescence and can be used for this purpose only after having been reconstructed. Its only role in the luminescence analysis is limited to measuring the absorption spectra of the specimens required for introduction of corrections associated with the secondary absorption of the luminescence into their spectra (see # 107).

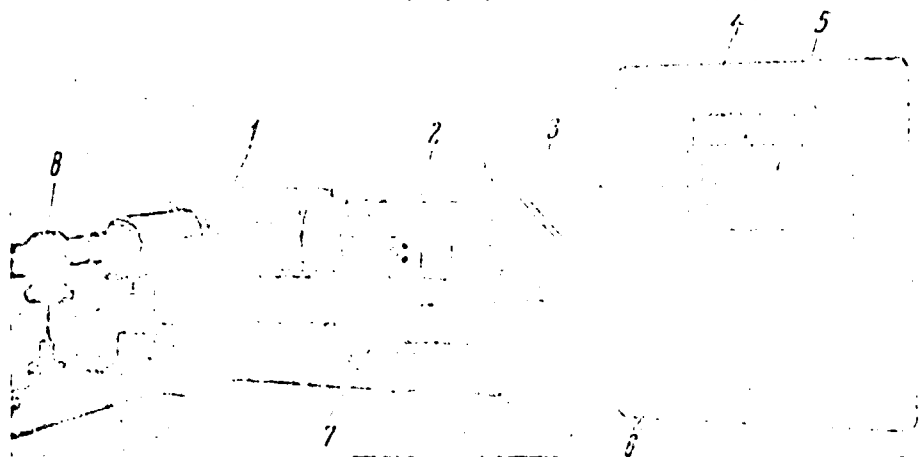


Fig. 194. A spectrophotometric installation with the photoelectric attachment FEP - 1:  
1 - spectrograph ISP -51; 2 - photoelectric attachment FEP - 1; 3 - receiving head;  
4 - recording device; 5 - automatic recording potentiometer; 6 - amplifier elements and feeding blocks; 7 - drum of the motor driving the spectrograph prismatic member; 8 - focusing condenser.

In laboratory conditions, often used is a spectrophotometric installation assembled on a principle of the universal monochromator, type UM - 2. Various models of a photo-amplifier (FEU - 17, FEU - 19, FEU - 22, etc.) can serve as a light receiver; they should be placed immediately after the outlet slit of the monochromator. The photo-amplifier is connected with a precision galvanometer whose deflections change with the luminescence intensity of the given wave-length.

Much more efficient is a similar, but factory-assembled, installation, designed to measure the luminescence spectra in their visible part. Figure 194 shows the assembled apparatus. The monochromator function is here performed by a type ISP - 51 (or ISP - 53) spectrograph after its camera is replaced by a photoelectric attachment FEP - 1. Its lens has a focal length of  $f_2 = 300$  mm. and the apparatus outlet slit is placed in the lens plane. Next to it is placed a photo-amplifier, type FEU - 17 whose signal can be amplified  $\sim 10^3$  times by means of a D. C. amplifier. The attachment is equipped with a motor which drives the spectrograph prisms, and thus projects various portions of the luminescence spectrum into the apparatus outlet slit, their intensity is then recorded by means of a photo-amplifier. The latter's signal is then fed to an automatic recording potentiometer PSI - 02, mounted in the recording device EPS - 157. Any deflection of the auto-recorder's pen is proportional to the light intensity of the luminescence. When the prism-housing element of the apparatus is rotating continuously and the diagram paper strip is moving too, the pen of the recording potentiometer will record the spectrum in the form of a continuous curve on which, in equal intervals, the marking lines have been indicated. The installation is equipped with a feeding device which provides a constant well stabilized voltage into the photo-electronic amplifier and to anodes of the D. C. amplifier tubes.

Also used is the obsolescent model of a photo-electric attachment - the output collimator, type PS - 381, in which the spectrum is being recorded on a photographic paper. Another variety of the above - the output collimator, type PS - 382, has a camera lens with a focal length of  $f_2 = 200$  mm., and thanks to it, the linear dispersion of the apparatus is almost three times as high. The output collimator PS - 382 contains two photo-amplifiers - the FEU -17 (with antimony-cesium photo-cathode) for operation in the blue-green part of the spectrum, and the FEU -22 (with oxygen-cesium photo-cathode) for operation in both the yellow-red and the near infra-red parts of the spectrum. Depending on the radiance color, by means of a prism for a full inner reflection, the luminescence spectrum can be directed to either of the above two photo-amplifiers. Figure 195 shows the arrangement of the described installation.

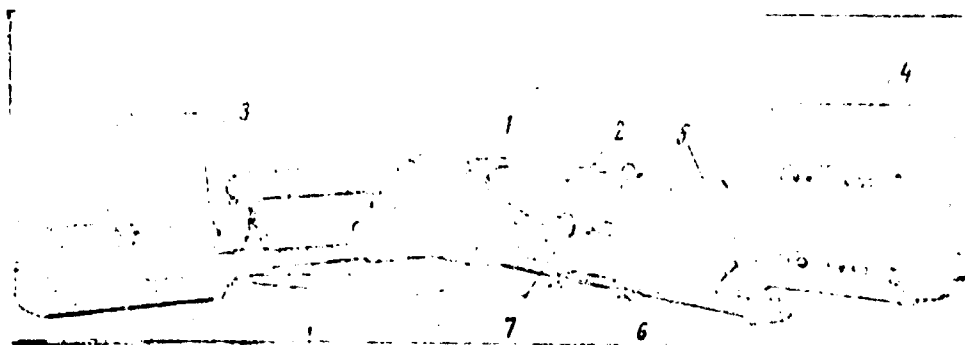


Fig. 195. The spectrophotometric installation with an output collimator PS - 382: 1 - spectrograph ISP - 51; 2 - output collimator PS - 382; 3 - recording device; 4 - feeding device; 5 - photo-amplifiers; 6 - amplifier; 7 - drum of the motor driving the prism-housing part of the spectrograph.

Before the metering is started one should calibrate the spectrographic installation by the wave-lengths. For this purpose the inlet slit of the wave-spectrograph shall be illuminated from a source of light with a linear spectrum whose individual lines wave-length is well known (for example that of a mercury-helium lamp). Using the obtained spectrum, one can establish the relation between the wave-lengths and the divisions on the drum mounted on the motor which rotates the prism-housing part of the spectrograph; after that, one can plot the dispersion curve of the apparatus.

Due to the circumstance that both the photo-amplifier sensitivity and the apparatus dispersion are a function of the light wave length, to measure the energy distribution in a spectrum, one should preliminarily re-calibrate the apparatus on any standard source whose distribution of energy in spectrum is well known. An ordinary incandescent lamp with a known color temperature\* can serve as such a standard source. The energy distribution in the emission of the lamp tungsten filament, in the range of a visual spectrum, will accurately enough coincide with the energy distribution in spectrum of an absolutely black body.

During the calibrating process, the inlet slit of the spectrograph should be illuminated by a standard lamp. At the same time, one should rigidly maintain a constant current at which the lamp's color temperature has been determined. Unless this condition is satisfied serious errors in the calibration will occur.

The magnitude of a deflection  $I_{obs}$ , as shown by the galvanometer for a certain wave-length  $\lambda$ , can be found from the following formula:

$$I_{obs} = I_{act} K_{\lambda} D, \quad (19.1)$$

where:

- $I_{act}$  - The actual intensity of the standard light source within the wave-length  $\lambda$ , as taken from tables, selecting a figure which corresponds with the color temperature of the standard lamp, and is expressed in units of the galvanometer scale, when  $K_{\lambda} = 1$  and  $D = 1$ ;
- $K_{\lambda}$  - Sensitivity of the photo-amplifier within the wave-length  $\lambda$ ;
- $D$  - Dispersion of the spectrograph (in  $\text{\AA}/\text{mm}$ ).

consequently,

$$K_{\lambda} D = \frac{I_{obs}}{I_{act}} \quad (19.2)$$

Having performed similar calculations along the entire spectrum, we will determine  $K_{\lambda} D$  as a function of  $\lambda$  - a curve for the apparatus sensitivity. To obtain the actual spectrum of the luminescence, ordinates of the experimental curve  $I_{obs} = I_{act} (K_{\lambda} D)$  should be divided by the corresponding ordinates of the sensitivity curve.

Besides the luminescence spectra, the described apparatus facilitate a study on the process of extinguishing the luminescence, as well as on the fading

\* The "color temperature" of a source - is such a temperature of an absolutely black body when the energy distribution in its spectrum coincides with that in the spectrum of the source itself.

away of radiance of the specimens which have a long after-radiance.

There are also spectrophotometric installations where monochromators with diffraction grating are used. Such apparatus are characterized by a high light power and angle dispersion and can embrace a wide spectral range. They are good for a work with variable photo-amplifier which are most sensitive to different parts of spectrum. Their signals are being recorded by means of automatic recording potentiometers (type EPP - 09).

### #103. Polarimeters and Polariscopes

The polariscopes and the polarimeters are used for the detection of a radiance polarization and metering it, respectively. Their main components are either the polarizing prisms or polaroids which function as the polarizers or analyzers. The degree of polarization can be measured either visually or by a photo-electric method. Of the visual devices the most widely used are the polarimeter designed by Cornut and the polariscope by Savard.

The Cornut's polarimeter (Fig. 196 a) consists of a Wollastone's prism "W" and any other polarizing prism "G" (usually, the Glann's prism). By rotating the dial "L" the prism "W" can be set in such a position that the oscillation direction of the light vector of one of the passed through light fluxes "I", would coincide with the direction of the maximum oscillations of the luminescence radiance; also the oscillation direction of the second flux "I<sub>2</sub>" would coincide with the direction of its minimum oscillations. As a result, when passing through the Wollastone prism the luminescence light will split into two light fluxes "I<sub>1</sub>" and "I<sub>2</sub>" polarized in two planes at 90° to each other. If the luminescence was only partly polarized, the two fluxes will have a different intensity. The latter can be made similar for both fluxes by turning the second polarizing prism (the analyzer) by an angle "α" which can be calculated from the following equation:

$$\frac{I_2}{I_1} = \tan^2 \alpha \quad (19.3)$$

Hence the degree of polarization will equal

$$P = \frac{I_1 - I_2}{I_1 + I_2} \frac{1 - \tan^2 \alpha}{1 + \tan^2 \alpha} = \cos 2\alpha \quad (19.4)$$

Experimentally, the 2α angle can be found as an angle by which the analyzer should be turned between its two positions where the intensity of the flux "I<sub>1</sub>" and that of the flux "I<sub>2</sub>" are equal.

The Savard's polariscope "P" (Fig. 196 b) consists of a Savard's plate and an analyzer (Nicol's prism). The Savard's plate is made of two quartz membranes cut out at an angle of 45° in relation to their optical axis, and put together in such a way that their main sections are at 90° to each other. When a partly polarized light has passed through both the Savard's plate and the Nicol's prism, a system of parallel interference strips can be seen in the vision field; these strips are the more distinct the more polarized is the tested light. With a sufficient intensity of radiance, the Savard's polariscope allows detecting the polarization degree of ~0.003.

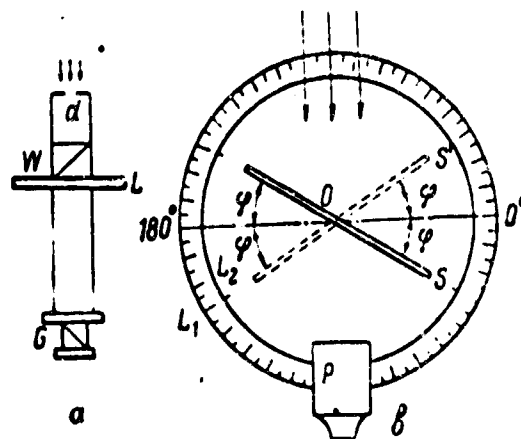


Fig. 196. a - Cornut's polarimeter;  
b - Savard's polariscope with a compensating pedestal

To measure the degree of polarization, attached to the Savard's polariscope should be a compensating device which in the passing-through light will generate polarization of an opposite sign. The pedestal "S" of the glass membranes can serve as such a compensator, it can rotate around an axis perpendicular to the direction of light beams and parallel to the direction of predominant oscillations of the light vector. Usually the installation is positioned in such a way that the pedestal will be rotated around a vertical axis. Turning the pedestal by a certain angle, marked on dial "L" one can attain the disappearance of the interference picture.

The Savard's polariscope has been significantly improved by V. V. Kavraiskii, whose apparatus has a high light-power and therefore is specially adapted to metering the polarization of objects with a weak radiance.

The pedestal should be preliminarily calibrated on any source emitting the radiance of a known polarization. One can use for this purpose incandescent lamps with frosted glass bulbs, whose light will pass through a polarizing prism. When the polarizer has been turned by angle  $\alpha$  in relation to a vertical line, the emitted light will have oscillations of the light vector and they too will form an angle with a vertical line. These oscillations can be broken down into vertical and horizontal components whose intensity will equal  $I_1 = A \cdot \cos^2 \alpha$  and  $I_2 = A \cdot \sin^2 \alpha$  respectively; here:  $I_1$  and  $I_2$  - two perpendicular to each other polarized components of the light flux, whose oscillations proceed in vertical and horizontal planes, respectively. When watching through an analyzer positioned in such a way that either the vertical or the horizontal component passed through, one can obtain a similar effect as if from a partly polarized light with its polarization "P" equal:

$$P = \frac{I_1 - I_2}{I_1 + I_2} = \frac{\cos^2 \alpha - \sin^2 \alpha}{\cos^2 \alpha + \sin^2 \alpha} = \cos 2\alpha \quad (19.5)$$

The angle  $\alpha$  is given different values from 0 up to  $360^\circ$ , each time calculating the degree of polarization from formula (19.5). Also, each time one should compensate the obtained value for polarization by turning the pedestal by a corresponding angle  $\alpha$ . Having thus obtained a calibrating curve which represents the degree of polarization calculated from the equation (19.5), as a function of the angle  $\alpha$  by which the compensating pedestal had to be turned, we can

use it for establishing the degree of luminescence polarization of any object by the magnitude of angle  $\alpha$ .

Regardless if the polarization degree is high or low, the pedestal should be adjusted in such a way that the interference lines disappear; this can be attained with a certain uniform absolute error which, in a case of intensive radiance, corresponds to a degree of polarization of 0.003. The relative error in the measuring of polarization degree will be different depending if the light polarization is strong or weak. A satisfactory accuracy of visual metering can be attained only at a high degree of polarization and at a considerable intensity of radiance. When this is the case, the relative error  $\frac{\Delta P}{P}$  3-5%. When the radiance polarization is going down, the relative error  $\frac{\Delta P}{P}$  will rise sharply. For example, when  $P = 0.05$ , the error will reach 37%. When the radiance intensity is low, the error in setting the pedestal so that the interference lines disappear is very high; particularly difficult is metering in the short-wave portion of the visual spectrum where the human eye is not very sensitive.

Photoelectric polarizing devices. The photoelectric methods are more sensitive and more accurate. They can be applied for metering the polarization of weakly radiating objects characterized by a blue-violet and ultra-violet luminescence. In the photoelectric installations, the excitation of the polarized luminescence is being effected in such a way that the maximum oscillations in the light flux take place in the vertical direction, the minimum ones - in the horizontal direction. Directly before the light receiver a polarizing prism or a polaroid (analyzer) is placed, oriented in such a way that the light vector oscillations at its certain position, were directed vertically, at another - horizontally. After we have measured the light fluxes  $I_1$  and  $I_2$  from formula (18.2), we can calculate the degree of polarization of the analyzed radiance.

For example, the above method has been used by B. Ya. Sveshnikov in his design for a photoelectric polarimeter-photometer shown in figure 197.

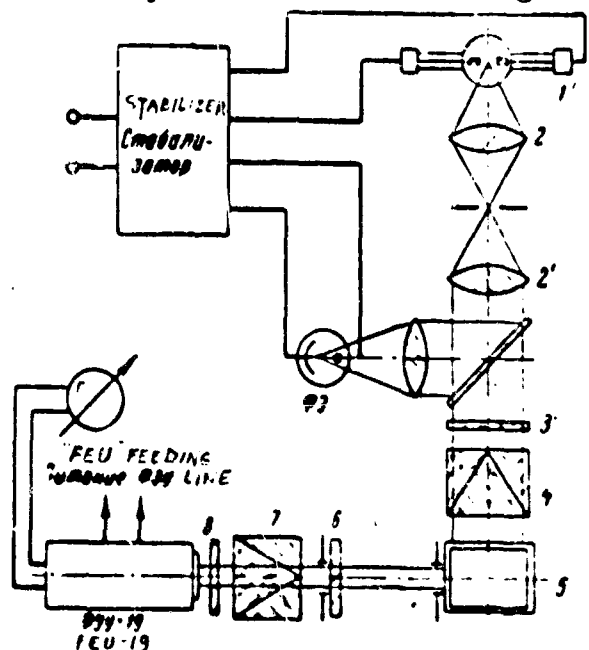


Fig. 197. Optical principle of the photoelectric polarimeter-photometer



## #104 Phosphoroscopes and Fluoroscopes

Phosphoroscopes are used for metering the duration and the process of luminescence fading away, and they have a range from  $10^{-1}$  down to  $10^{-7}$  seconds. When the duration of the after-radiance is less than the above ( $\sim 10^{-8} - 10^{-10}$  seconds), the metering can be carried out by means of fluorometers.

Phosphoroscopes. The general principle of operation of all phosphoroscopic installations consists in a momentary excitation of the luminescence in the substance to be investigated, and in studying its after-radiance. Used are two methods of phosphoroscopic observations. The first one consists in watching the fading away of radiance of a fast moving object which was previously excited for a very short time. Individual stages of the fading away process can be studied by observing the radiance at a various distance from the place of excitation. The second method, consists in watching the radiance brightness of a previously excited stationary specimen in its certain stage of fading away.

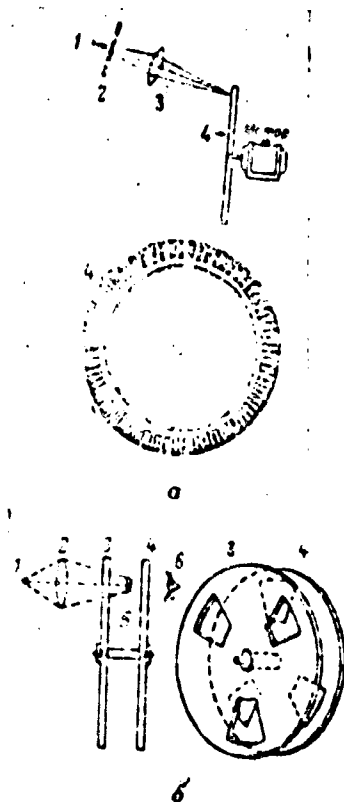


Figure 198. The Phosphoroscopes

- a) Single-disc type; 1- source of excitation; 2- filter; 3- condenser; 4- disc; b) Double-disc type; 1- source of excitation; 2- condenser; 3 & 4- discs; 5- substance; 6- watcher's eye.

The method No. 1 is being used in a single-disc phosphoroscope (figure 198,a); the latter represents a disc with the investigated substance spread along its

In the above apparatus, the luminescence is being excited by means of a high-pressure mercury lamp, type SVDSH - 250 (1) whose radiance has been stabilized as it has been described in #87 through a filter (3) and a polarizer (4), the exciting light is directed to a vessel (5) containing the substance to be analyzed. The latter's radiance directed at  $90^\circ$  to the exciting light beams and passing through a light-filter (6) and an analyzer (7) will be recorded by a photo-amplifier FEU - 19. A "quarter wave-length" membrane (8) has been placed before the photo-amplifier. Its function is eliminating the polarizing effects on the photo-amplifier's cathode.

The metering of the luminescence polarization degree is thus reduced to recording the intensity of radiance at two positions of the analyzer - the parallel and the perpendicular to the oscillation plane of the electric vector.

One can also apply a different approach. A partly polarized luminescence light is passed through a Wollastone prism positioned in such a way that the two outgoing separate light fluxes, with the light vector oscillations, in two mutually perpendicular planes, would have the same magnitude as " $I_1$ " and " $I_2$ " of the luminescence light. To have them recorded, the two fluxes are then directed into two photoelectronic amplifiers. In such an installation, one should very accurately consider a possible discrepancy of sensitivity as well as other characteristics of both receivers.

Intensity of the radiance to be measured is usually small and thus, it becomes necessary to amplify the signal by means of A. C. amplifiers which have a better stability than the D. C. units. In this case one should preliminarily modulate the intensity of the light flux to be measured; there are several ways of modulating. For example, across the path of a partly polarized light flux one can place a rotating polaroid which periodically changes the intensity of the passing through light. Here, the depth of modulation will vary with the degree of the luminescence polarization. Under the modulated light flux, a modulated photo-current will form in the receiver, this current will be then amplified in an A. C. amplifier and measured by any electric meter.

In some photoelectric installations, a compensation method is being used for metering the polarization degree. The compensation can be attained by means of either glass or quartz pedestal which should be preliminarily calibrated by a source which emanates radiance with a known degree of polarization.

edge. The disc is mounted directly on a shaft of a motor, and is rotated by same. The luminous substance which has been excited in a certain point on the disc, is changing its place when the latter rotates. Different moments of fading away correspond to different positions of the substance; as if the radiance was unrolling itself with the time. Having measured the brightness of radiance in various spots, one can establish the law of fading away. The single-disc phosphoroscope is capable to measure the duration of after-radiance up to  $\sim 10^{-5}$  sec.

The fact that the substance has to rotate fast makes the single-disc phosphoroscope not very suitable for study on how much various outside factors (for example, the temperature) are affecting the fading-away process. In such a case, recommended is the second method where a double-disc phosphoroscope is being used (the Bequerel phosphoroscope). The apparatus consists of two discs (3 & 4) mounted on a motor shaft (Figure 198, b). Both discs have a number of openings staggered in relation to one another. The excitation source (1) and the watcher's eye (6) are positioned at either side of the discs, the luminescing substance (5) - in between the same. When it is being excited, the substance remains hidden from the watcher behind the disc (4). Next, both discs make a turn. The disc (3) will cut off the excitation, and the watcher will see the radiance through opening in the disc (4). By changing the distance between the openings, and also the speed at which the discs are rotating, one can watch the after-radiance at different intervals of time, after the excitation has been stopped. A double-disc phosphoroscope can measure the duration of after-radiance up to  $\sim 10^{-4}$  seconds.

Quite often, apparatus are used which are performing on the principle of a double-disc phosphoroscope but have just a single disc with a number of openings at a certain angular distance from one another. The object to be investigated should be placed on one side of the disc, the source of excitation and the receiver - on the other. After the light from the source has passed through one of the openings, turning the disc by a certain angle will interrupt the excitation. At the same time, the radiance of the investigated object is being watched through another opening. Next, the objects becomes cut off from the receiver by the between-the-openings-space of the rotating disc, and, at the same time, a radiance will be excited through another opening again; etc.

The phosphoroscopes are designed for different values of the after-radiance duration, and of a minimum time interval which can be registered by them. These factors are interlocked, in other words, when one of them (the duration) is increased, the other one (the momentary discerning capability of the phosphoroscope) will inadvertently go down. As compared to the double-disc type, the single-disc phosphoroscope is a more efficient apparatus, and it is given a priority wherever possible.

A successful model of photo-electric phosphoroscope ("Taumeter") has been worked out by N. A. Tolstoy and P. P. Feofilov (Figure 199). The object to be investigated (3) shall be illuminated by a mercury lamp (1); behind the object, mounted is a photo-amplifier, Type FEU-1 which records the excited radiance. The signal from the photo-amplifier is then fed onto the vertical plates "V" of a cathode oscillograph "KO". To eliminate any influence from the dissipated

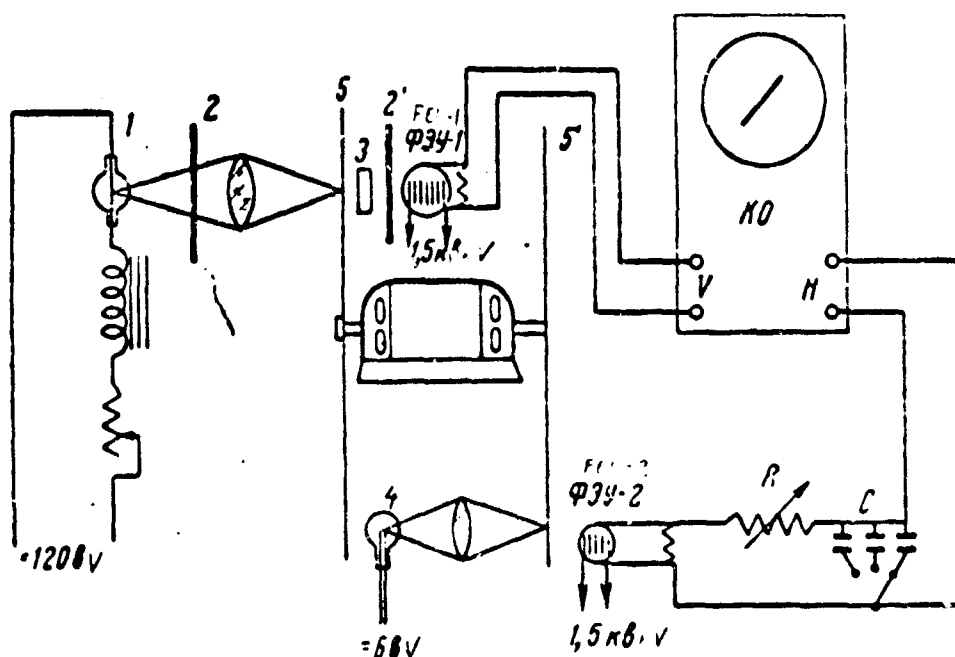


Figure 199. Diagram of a photo-electric phosphoroscope (Taumeter)

light, the investigated substance has been placed between two crossed light filters (2 and 2') [107]. The apparatus is also equipped with an incandescent lamp (4) whose light hits the second photo-amplifier FEU-2 which is connected to horizontal plates "H" of the cathode oscillograph by a circuit consisting of a variable resistance "R" and variable resistance "R" and variable capacity "C". The purpose served by this part of the apparatus - converting an ordinary, linear relation of the oscillograph horizontal output to the time, into an exponential function. Mounted on the shaft of the taumeter motor, are two discs (5 and 5') with openings which are interrupting the respective light of lamps (1 and 4) with the same frequency and in phase. Here, the deflection of the oscillograph beam directed horizontally (direction of the time) will satisfy the following equation:

$$X = X_0 e^{-t/RC} \quad (19.6)$$

Deflection of the beam in vertical direction is in a straight proportion to the radiance brightness, and, with an exponential law of fading away, will be as follows:

$$Y = Y_0 e^{-t/\tau} \quad (19.7)$$

By varying the values of R and C, one can attain the equality of the exponential multiple in equations (19.6) and (19.7). In such a case, the oscillogram will be a straight line. Knowing the values of R and C for this particular case, one can estimate the value for  $\tau$  using the following equation:

$$\tau = RC. \quad (19.8)$$

A taumeter can measure  $\tau$  in the interval from  $10^{-1}$  down to  $10^{-5}$  second. When the radiance is intensive, the error of the readings is negligible ( $\sim 1\%$ ).

A more advanced apparatus - an ultra-taumeter- designed by N. A. Tolstoy and his associates, has a similar principle of operation. Here, the radiance is being excited by rectangular light impulses with a curvature of their front and rear heads equal  $\sim 10^{-7}$  seconds. The apparatus electric circuit has an inertness of  $\sim 10^{-7}$  seconds, too. The ultra-taumeter can measure the duration of after-radiance down to  $2 \cdot 10^{-8}$  seconds.

Fluorometers. These apparatus are being used for metering processes of even a shorter duration. Such a momentary radiance usually fades away according to either the exponential law (18.6) or a law very close to exponential. If the excitation is being effected by a modulated light (with a cyclic frequency of modulation  $\omega$ ). Then the created luminescence turns out to be modulated, too; however, with an exponential fading-away of the radiance, the luminescence modulation lags in its phase from that of the excitation, by an angle

$$\varphi = \arctg(\omega \tau). \quad (19.9)$$

With the modern phase fluorometers, one can measure the value  $\varphi$  directly, and then, from the formula (19.9), one can calculate the magnitude of  $\tau$ . For a high-frequency modulation of the exciting light, they use here the diffraction on a standing supersonic wave generated by a high-frequency field in either piezoelectric crystal or a liquid (for instance, in xylol) into which a piezoelectric plate has been immersed.

Figure 200 shows the diagram of a phase-type fluorometer. Modulated by a piezoelectric crystal (3), the light beam is then divided into two flows by means of a semi-transparent light-distributing membrane (6). The first of the flows is reflected in a system of mirrors (9, 9', 9'') and in a dissipating screen (7), and then enters the photo-amplifier FEU-1; the second flow is directed at the investigated object (8), and excites a modulated light of luminescence which is then recorded by the second photo-amplifier FEU-2.

Signals from the two photo-amplifiers are entered into two inlets of a symmetrical, two-channel phase-metering apparatus whose phase-indicator has a pointer-and-scale device G. The latter's readings are the function of the phase difference between the signals fed into the inlets of the phase-metering installation. The fluorometer readings are taken by the zero method, and for this purpose the phase difference in both light flows should be compensated. The compensation can be effected by means of a special electrical, multi-step phase-rotating device, or by changing the length of the optical path in the

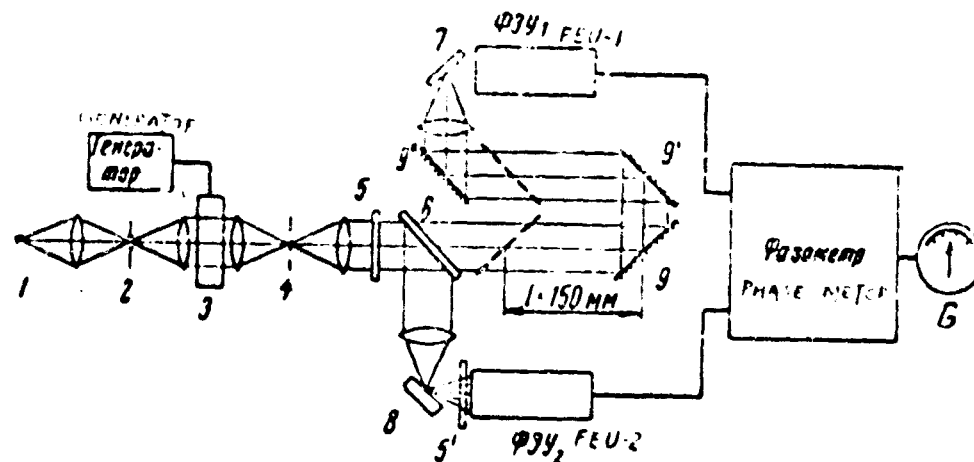


Figure 200. Optical diagram of the phase-type fluorometer:<sup>14</sup>

1- light source; 2,3,4- members of optical modulator; 5,5'- crossed light filters; 6- light distributing membrane; 7- dissipator; 8- object to be investigated; 9,9',9''- mirrors; FEU-1, FEU-2 - photo-amplifiers; G- galvanometer

comparison channel (mirrors 9 and 9' are movable). In case the fading away process is proceeding according to exponential law, with a negligible error the fluorometer can measure the after-radiance duration of  $\tau \sim 10^{-10}$  seconds.

#### #105. Special Apparatus Used in a Qualitative Luminescence Analysis

For a qualitative luminescence analysis, used are apparatus called "The Luminoscopes." The most simple of them is the sun luminoscope used in field for watching the luminescence of rocks and minerals. It consists of a small box with a top made of black glass; the mineral to be analyzed will be placed on its bottom. The radiance excited by the sun beams penetrating through the black glass, can be watched through an opening in the box side wall.

Other types of luminoscope are equipped with a source of ultra-violet rays, and from its spectrum light-filters will separate different zones. Let us discuss some of the luminoscopes.

The Universal field luminoscope, type PLS-53 is destined for a qualitative luminescence analysis of minerals and other objects in the field conditions. The excitation is being effected either by the filtered ultra-violet light of the sun ( $\lambda_{\text{max}} \approx 365 \text{ m}\mu$ ) or by the filtered light of an incandescent lamp ( $\lambda \approx 400-460 \text{ m}\mu$ ). The object to be investigated shall be pressed to the apparatus base, and its radiance can be watched through the eye-piece.

Luminoscopes, types "Polyus" and LYUM-2 are designed for a qualitative luminescence analysis of minerals (scheelite, zircon, uranium minerals, etc) whose radiance is being excited by the short-wave, ultra-violet radiation of mercury lamps, type PRK-2 (LYUM-2) and type PRK-4 ("Polyus"), which are performing in conditions of the glow discharge. In this case, the main part of the emanated energy is concentrated in the resonance line of the mercury ( $\lambda = 253.7$ ). Filter, type UFS-1, is being used for absorption of the visual light. The "Polyus" apparatus is equipped also with a direct vision spectro-scope which allows classifying various uranium minerals, with their specific luminescence spectra.

Luminoscope for analysis of liquids are similar in their design to those described above. They have special holders for test tubes containing the substance to be investigated, and the standard one with a known characteristics.

Luminaires. For the purpose of luminescence analysis, widely used are special luminaires which contain a source of ultra-violet emission. Particularly efficient is the luminescent, analytical lamp, type LYUM-1, which contains a mercury lamp, type PRK-4, with a reflector. Its emission exits through a UFS-3 filter ( $\lambda_{\text{max}} = 365$ ). A type PUF-2 VNISI apparatus, with a mercury PRK-2 lamp as a source of ultra-violet rays, has a similar application. In those cases when a less powerful ultra-violet radiation is sufficient (detection of defects by way of luminescence), used are special luminescent lamps, type L-350, whose bulb is covered by crystallo-phosphori, type L-33, which emanate a sufficient amount of ultra-violet rays. This type of lamps is used, for instance, in the luminaire PUF-5 VNISI.

For a powerful, concentrated beam of ultra-violet rays, used is the luminaire OS-65 which consists of a high-pressure mercury-quartz lamp, type SVD-120 with a reflector, and of a light-filter UFS-4.

#### #106. Luminescent Microscopes

Many problems of the modern biology and medicine are being solved by means of luminescent biologies. From the ordinary microscopes they differ by the fact that the investigated object becomes visible not on account of the let-through or reflected light, but thanks to its luminescence which has been excited by either ultra-violet or short-wave, visible rays. The luminescent microscopes have a source of ultra-violet rays which should pass through their optical system. That's why the microscope optical system is made either of quartz or fluorite. The electric arc, and also the high and super-high pressure mercury lamps can serve as a source of excitation.

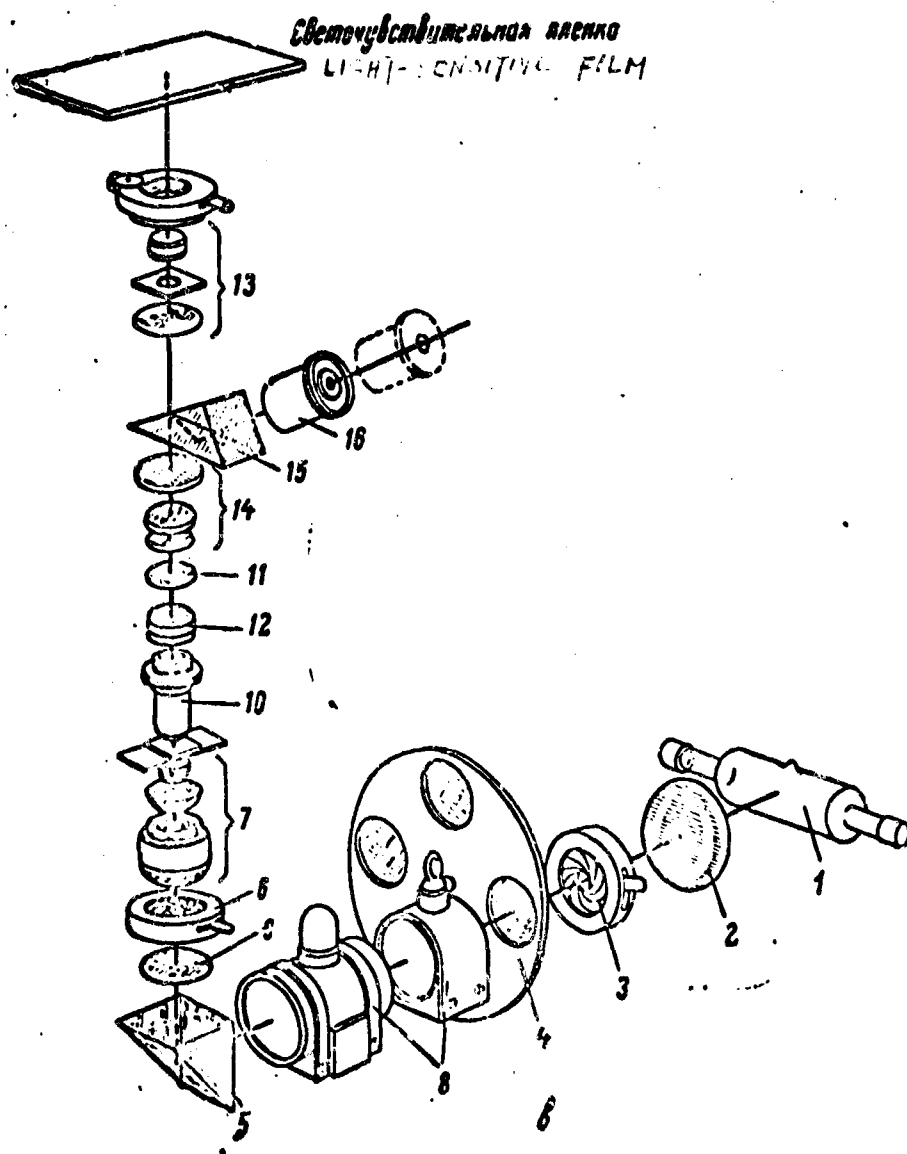
The luminescent microscopes are built in such a way that the exciting light can either pass through the specimen to be analyzed, or drop from above, through the microscope lens, down on the specimen surface. The former method of excitation is being used when investigating thin specimens, without any absorption. The latter method - for investigating heavy, non-transparent specimens - frequently found in both the geological and metallurgical research. This type of microscope is also helpful in studying various organs and non-transparent tissues of living organisms.



Figure 201. Luminescent Microscope, Type MUF-2:

- a- general view of apparatus when performing in reflected light;
- b- diagram of optical system when performing in passing-through light.





Luminescent microscope type MUF-2. The type MUF-2\* turns out to be the most efficient of all the Soviet-made luminescent (ultra-violet) microscopes. Figure 201,b, shows the diagram of its optical system. Light from the lamp (1) type PRIC-4 (or SVD Sh-250), by means of a condenser (2) and swivel prism (5), is being projected at a diaphragm (6) with apertures; by means of a condenser (7), the diaphragm is projected at the inlet eyepiece of the micro-lens (10). By means of a prism (5) and a condenser (7), the field diaphragm (3) is projected at the object surface. With this method of illumination, the light flux of the source (1) is used most efficiently. The investigated object is uniformly illuminated over the entire range of the diaphragm (6) opening.

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\* With the MUF-2 apparatus one can investigate in the ultra-violet rays, not just the luminescing specimens, but also substances with no luminescence capability; therefore, the above apparatus is frequently called an "ultra-violet microscope."

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In the luminaire, three removable filters are mounted in a revolving disc (4). One is made of glass UFS-1 (to separate the range 400-250 m $\mu$ ), the second of glass UFS-3 (to separate the mercury line 365 m $\mu$ ), the third - of glass, types TF5 and NS-2. The latter filter is being used when tuning the apparatus in order to project live organisms from a lengthy exposure to ultra-violet rays which might be lethal. The apparatus is equipped with liquid and gaseous light-filters (8). The gaseous filter consists of a quartz vessel filled with a gas mixture of chlorine and bromine. This filter will separate the spectral zone of from 280 down to 250 m $\mu$ . The liquid filters consist of quartz vessels, too, filled with a fluid of a specially selected composition. These are used in combination with gas filters, and they can separate narrow zones of the specimen, as approximately  $\lambda = 280, 265$  and  $254$  m $\mu$ . One of the liquid filters, containing diluted potassium chromate, when combined with the glass filter UFS-1, can separate the mercury line 313 m $\mu$ . The apparatus is also equipped with eight ordinary light-filters (9) made of various types of colored glass, which are being applied when working with the visible light.

When taking a picture of the investigated object, its image can be projected on the film by means of the lens (10) and ocular (13). For a visual observation of the specimen under ultra-violet rays, one can use a luminescent converter which consists of an achromatic block (12), luminescent screen (11), lens (14) and a swivel prism (15). In this case, the object image will appear on the luminescent screen (11) and can be watched through the ocular (16). The ocular position, as indicated by the dotted line, corresponds with the observation by way of the luminescent converter. When the latter is not available, the ocular will be in a closer position, suitable for observations in the rays of the visible light. When taking a picture, both the prism (15) and the luminescent converter are taken out of the path of the microscope beam. The optical scheme of the MUF-2 can be slightly re-designed to suit the work in a reflected light; for this purpose, the ultra-violet rays from the luminaire by way of an auxiliary optical system, should be directed at the object from above, through lens (10).

The MUF-2 apparatus can perform also in either the visible reflected or visible passing-through light. For this purpose, an extra luminaire, type 01-7, is attached which shall be mounted to the left from the MUF-2 microscope; here, the prism (5) shall be turned by 180°.

With the MUF-2 microscope, using a method worked out by E. M. Brumberg, one can take color micro-pictures of objects while in the ultra-violet zone; in ordinary conditions. The picture comes out black-and-white. Using a three-dimensional camera, one takes three negatives in various wave-lengths and in the ultra-violet zone; next, three positive pictures shall be made of the negatives. Due to the fact, that the object will absorb the three wave-lengths in a different way, the dark spots on the film will be different, too. To receive the color pictures, the positive picture should be placed in a special apparatus called "chromoscope," which is attached to the MUF-2. In the chromoscope, each of the pictures is penetrated by red, green and blue rays, respectively. Using mirrors, the images of all three pictures are then combined in a single field of vision. As a result, the watcher will see in his ocular, a contrast colored image of the investigated object, with variously colored individual details. The above method considerably facilitated the observation of the specimen details, and added to the advantages of the ultra-violet microscope.

Luminescent Micro-Spectrometer, Type LMS-1. This apparatus can be used for a qualitative luminescence analysis of microscopic grains of uranium and other minerals. The analysis consists in comparing the luminescence spectra of standard specimens with those of the object to be investigated. Ultra-violet rays are exciting the radiance in both objects at the same time; their light then passes the microscope and a special optical system, and arrives at a spectroscop of a direct vision. The watcher will see two spectra, one above the other and separated by a thin dividing line. By comparison, one can immediately establish if the investigated specimen is similar to the standard, or differs from it.